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Effective ways to reduce leaching and formation of efflorescence on structures

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Abstract. Corrosion of the first kind (leaching) is the process of dissolution and removal to the surface of the structure of calcium hydroxide salts mainly under the action of a constant diffuse flow of water through a multi – level porous structure of the concrete composite. Technological methods to prevent the formation and reduction of efflorescence (leaching) when used in practice, improve durability of building structures and reduce operating costs. The paper explores the possibility of reduction or complete elimination of efflorescence on the surface of building structures due to the impact on calcium hydroxide in the composition of the Portland cement.

1. Introduction

In the modern world high requirements are imposed to the erected building structures of buildings and constructions not only on stability and reliability to various types of external aggressive influences of environment, but, in particular, and to durability at operation at atmospheric influences [1,2]. As a result of the influence of mass transfer through building materials, salt crystals are formed on their surface, and building structures of these materials change their performance characteristics. The development of effective methods to counter these phenomena, which are engaged in the Department of materials Science in construction at Institute of new materials and technologies of Ural Federal University, is impossible without studying the mechanism of physical and chemical processes occurring in the concrete composite. The mechanisms of the process of salinization are revealed.

2. Results and discussion

Efflorescence is a crystalline neoplasm on the surface of building structures that occur due to two parallel processes:

- chemically non-bound water (moisture) interacts in the body of the Portland cement stone composite with highly soluble substances (calcium hydroxides, magnesium, calcium sulphates and other substances) to form a saturated solution of these salts;
- under the influence of the temperature gradient, the solution migrates to the outer porous surface of building structures (concrete, mortar or brick), followed by crystallization by evaporation of water.

It is well known that concrete (multicomponent composite of agglomerate structure with Portland cement cementation) has a number of defects of micro and macrostructure. In the structure of the monolith can be conditionally identified the main types of defects: weakened areas of contact with the

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surface of the cement stone aggregates, the place of contact of the filler grains without cement stone, microcracks micro and macropores. The latter are formed due to the evaporation of excess water that is not involved in the reactions of hydration of clinker minerals and are one of the reasons for the transfer of salt solutions in the body of the concrete [3-5].

The main causes of efflorescence are:

- presence of humidity and temperature gradients perpendicular to the facade in the building structure;
- the presence in the structure of artificial building material (portland cement composite or ceramic brick) pore system, microcracks and capillaries, allowing the migration of salt solution;
- formation of chemical compounds with high solubility in water, the main of which is calcium hydroxide, in the process of portland cement hardening;
- application in the production of concrete works of salt chemical additives, mainly providing frost resistance;
- soluble components of inert filler materials may contain salts that can pass into solution;
- external flow of mineral salts during the operation of structures due to groundwater or man-made water (capillary suction).

Of the above reasons, the effect of the moisture gradient can be reduced only by structural method, performing the design of thermal calculation of the outer wall, thereby pre-determining the required thickness and composition of materials, or further warming it during construction and subsequent operation.

The number of capillaries in the structure of hardened concrete or mortar correlates with the estimated characteristics of concrete (water resistance) and decreases with the introduction of modern chemical additives designed to increase this characteristic.

If we consider the third reason, the hardening of Portland cement occurs due to hydration reactions of clinker minerals. At the same time, $3CaO \cdot SiO_2$ (containing up to 60 %) and $2CaO \cdot SiO_2$ (up to 20%) prevail in modern Portland cement. Hydration occurs by the following reactions:

$$2(3CaO\cdot SiO_2) + 6H_2O = 3CaO\cdot 2SiO_2\cdot 3H_2O + 3Ca(OH)_2 \quad (1)$$

$$2(2CaO\cdot SiO_2) + 4H_2O = 3CaO\cdot 2SiO_2\cdot 3H_2O + Ca(OH)_2 \quad (2)$$

Consequently, the formation of calcium hydroxide is inevitable when hardening Portland cement in concrete or cement-sand solution.

From the fourth to the sixth reasons do not make a significant contribution to the problem and are not mandatory for all objects with efflorescence, and even more so are not decisive. Thus, the efflorescence on the surface of the concrete structure or brickwork are:

- indicator of moisture gradient crossing the structure, including the inefficiency of waterproofing;
- a factor that reduces the aesthetics of the building facades;
- the cause of mechanical stresses of the surface layer at the micro level;
- the result of the formation of micro-voids in the composite structure of concrete or cement mortar brickwork.

Study the possibility of reduction or complete elimination of efflorescence on the surface of building structures due to the impact on calcium hydroxide in the composition of the Portland cement composition is the most promising and versatile. Research in this direction is carried out by the authors. Cement gel-an aqueous colloidal solution saturated with Portland cement hydration products-is an undeniable component of the cement stone structure. Also a component of the structure are capillary voids-residual space, originally filled with physico-mechanically bound water, evaporating during the hardening of concrete. The porosity of concrete can be reduced by reducing the amount of water in the concrete mixture (using plasticizing additives) or by changing the method of forming

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structures (self-compacting concrete mixtures, air removal). Capillary porosity of concrete is usually determined by the method of Gorchakov G. I. [6-10] by the formula:

$$P_C = \left(V - C_o \cdot C\right) \cdot 10\% \tag{3}$$

where B - water consumption per 1 m^3 of concrete, kg; C - cement consumption per 1 m^3 of concrete, kg; C_o - fraction of chemically bound water in parts by weight of cement (usually 0.15-0.2).

Microscopic studies have shown a decrease in the rate of formation of efflorescence over time due to the carbonation of the surface layer of concrete. This phenomenon occurs to a depth of 20-30 mm from the outer surface of the concrete and consists in the reaction of calcium hydroxide in the pores and capillaries with CO_2 from the air. In this slightly soluble compound $CaCO_3$ collateral pores, thereby reducing the possibility of entering a saturated solution to the surface. This increases the water resistance of concrete. Another possible method of reducing the efflorescence consists in introducing into the composition of the cement composition components which will react with calcium hydroxide with formation of insoluble compounds, for example calcium hydro-silicates [6-8,11-20]. Such additives are called "active mineral" and the most effective of them is diatomite.

Generally accepted is the method of determining the speed and amount of formation of efflorescence, simulating the work of structures in operation. In this case, the samples of fine-grained concrete are placed in the laboratory vertically, with the lower part of the sample at some depth immersed in liquid (most often water, less often-in salt solutions). After a certain period of time, determine the height of the liquid in the sample, the number of tumors on the surface (Figure 1).

Figure 1. Samples in the process of testing.

The authors used Portland cement CEM I 42.5 and quartz river sand of local manufacturers to make samples of fine-grained cement composite composition 1: 3. Samples of the control (0-0) and basic compositions solidified under normal conditions (temperature 20 ± 5 C and humidity 95 ± 5%) for 28 days. During the tests, the samples were kept for 28 days under normal conditions in a vertical state, submerged in water for 1 cm, and then determined the height of the liquid in the samples and the mass of the tumor on their surface.

To study the effect of capillary porosity reduction on leaching processes on the samples of the main compositions, a plasticizer based on polycarboxylate esters reducing W/C ratio (Table 1) was used. To bind $Ca(OH)_2$ to insoluble compounds, diatomite crushed to the thinness of Portland cement (Table 1) was introduced into the composition.

Table 1. Composition and characteristics of experimental concrete composites.

N of mix	number of components (kg/m^3)			W/C ratio (%)	capillary porosity (%)	the height of liquid rise (mm)	the mass of efflorescence (g)
	water	plasticizer	diatomite				
0-0	200	-	-	40	11,5	150	6,2
1-0	190	1	-	38	10,5	123	6
2-0	180	1,5	-	36	9,5	98	5,8
3-0	170	2	-	34	8,5	86	5,6
4-0	160	2,5	-	32	7,5	70	5,4
5-0	150	3	-	30	6,5	63	4,9
0-1	200	-	10	40	11,5	136	5,2
0-2	200	-	20	40	11,5	122	3,6
0-3	200	-	30	40	11,5	120	3
0-4	200	-	40	40	11,5	115	2,4
0-5	200	-	50	40	11,5	110	1,8
5-1	150	3	10	30	6,5	42	3,5
5-2	150	3	20	30	6,5	26	2,4
5-3	150	3	30	30	6,5	24	1,8
5-4	150	3	40	30	6,5	20	1,2
5-5	150	3	50	30	6,5	13	0,6

After processing the results, it was experimentally established:

- reduction of W / C ratio (ΔP, %) leads to an increase in the homogeneity of the composite structure due to a decrease in capillary porosity, which is manifested in a significant reduction in the liquid lifting height (Hlq, mm) in the sample (Figure 2) and a slight decrease in the number of tumors (mcr, g);
- by introducing into the composition of the composite components (mdt, kg/m3), reacting with $Ca(OH)_2$ to form insoluble salts can achieve a significant reduction of tumors (Figure 3);
- no reduction in the capillary porosity, the height of liquid rise in the capillary system of the concrete will decrease slightly (Figure 4).

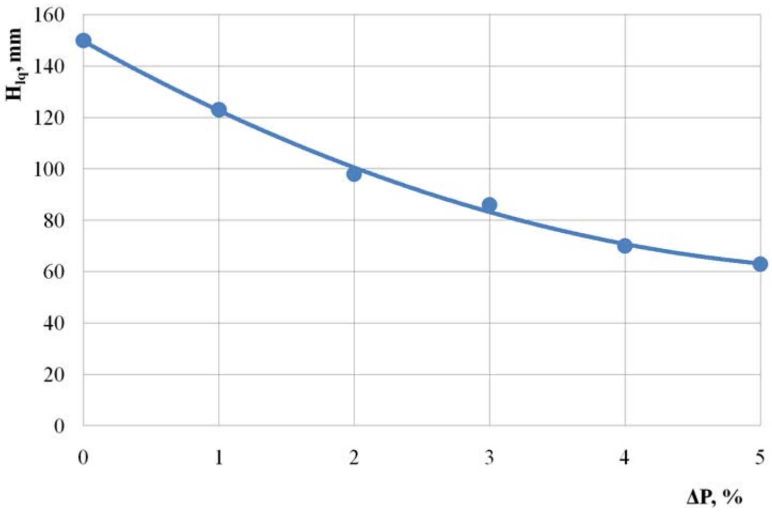

Figure 2. Reducing the height of the liquid in the sample by reducing capillary porosity.

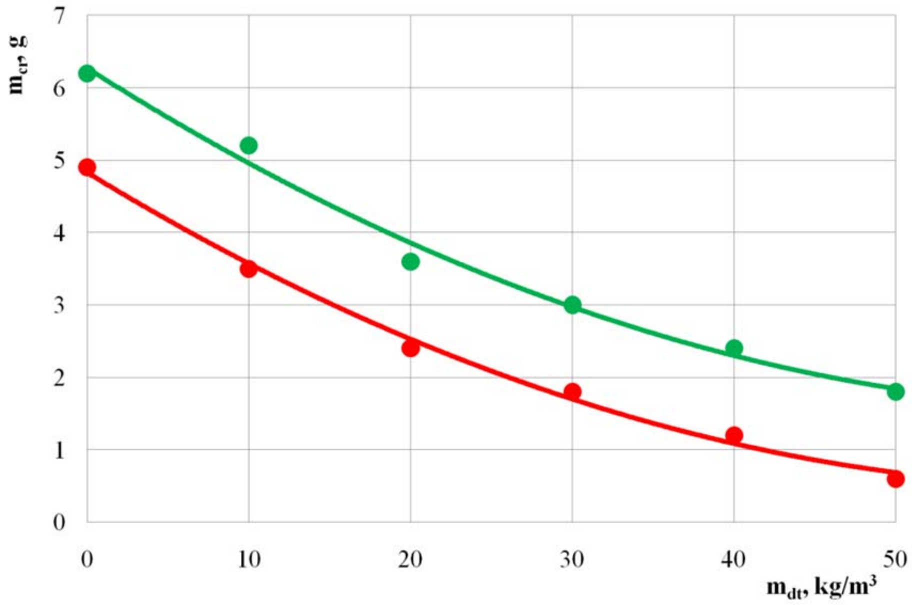

Figure 3. Reduced salinity due to reactions with Ca $(OH)_2$.

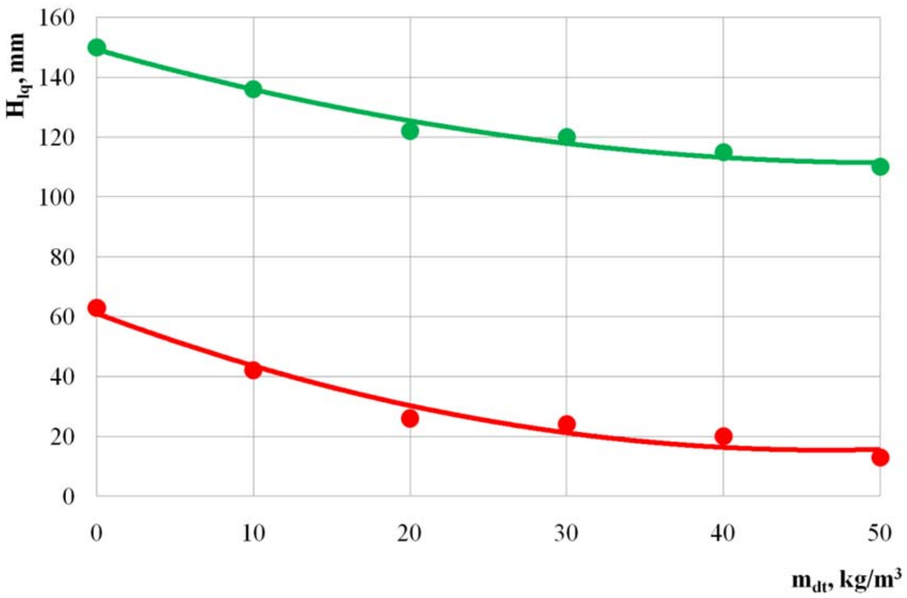

Figure 4. Reducing the height of the liquid in the sample by reducing capillary porosity.

3. Conclusion

The main characteristics of the process of salt formation on the surface of concrete (leaching) are the height of the liquid rise through the capillaries of the composite structure and the number of tumors on the surface of the structure. There are two methods to combat this type of corrosion: porosity reduction and the introduction of active components that react with Ca(OH)2 [9]. Both methods can reduce the negative consequences, but it is possible to achieve significant results only by applying them comprehensively. In the course of the research, the process of each of them was experimentally studied, as well as recommendations and methods for assessing the effectiveness of their application were developed.

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